Transient overvoltage protection: The implications of new techniques

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Reprinted, with permission, from *Proceedings, 4th Symposium on Electromagnetic Compatibility*, Zürich, 1981
Also appeared as a reprint in *The Electrical Engineer* (Thomson Publications, Johannesburg), October 1991

Significance:
Part 6: Tutorials, textbooks, and reviews
Part 7: Mitigation techniques

The paper presents a comparison of the performance of voltage-switching devices and voltage-limiting devices for late seventies-vintage SPDs as marketed and installed in service panels in the USA and in Europe.

Artifacts in the response of a typical oscilloscope to a nearby gap sparkover, and the effect of lead dress inside the panels and outdoor installation are described. Predictably, the performance of a metal-oxide varistor is found preferable to that of a gap-based arrester.

TRANSIENT OVERVOLTAGE PROTECTION: THE IMPLICATIONS OF NEW TECHNIQUES

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Summary

Reliability problems can occur from the use of modern electronic devices without applying appropriate protection techniques or using incorrect installation procedures. Although surge arresters are effective in limiting overvoltages, a metal oxide varistor can provide a much lower clamping voltage if installation procedures are taken into consideration. Sparkover voltage measurements, with a specified time rise, measured arrester performance. The response of the arresters to a current impulse was investigated and lead effects were identified. Tests indicated that the metal oxide varistor, installed with short leads, provides low clamping voltage.

Introduction

Incorrect protection for modern electronic devices from lightning strokes can cause reliability problems which could arise from various sources:

- Sensitivity of modern electronic equipment
- Improper procedures of installation
- Complete lack of protective devices.

This paper examines new applications of old concepts which are required by the constantly increasing use of electronic equipment; the particular increased sensitivity of these devices; and intense, competitive pressures.

We shall consider first the design and environment of surge arresters for low-voltage systems and then examine their performance as a function of installation.

Surge arrester design for low voltage systems

In the past, typical surge arresters (diverters) for service entrance duty have been limited to a gap-varistor design. This design involves gap sparkover voltage with a result of a relatively high clamping voltage for the arresters. The new, commercial availability of metal oxide varistors, with current ratings suitable for service entrance duty, provides a low clamping voltage at the service entrance.

Surge arresters, which have sufficient current discharge capacity, consist of a gap in series with a nonlinear resistor, usually a silicon carbide block (Figures 1, 2, and 3). These arresters are effective in limiting overvoltages to levels compatible with solid insulation. In recognition of this compatibility, the IEC Report 664 [1] proposes voltage levels of 2500 V for a 120 V circuit and 4000 V for a 220 V circuit (Table 1). However, these voltages are not consistent with the inherent withstand characteristics of electronic appliances. A much lower level (indicated by Category I or II of the 664 report) is required, i.e., 800 or 1500 V

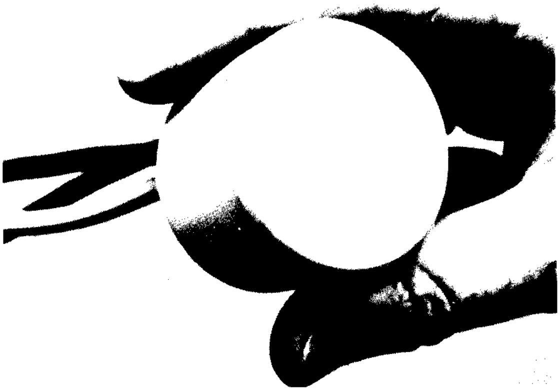


Figure 1: Surge arrester for 120 V circuits, service entrance or panel installation

Figure 2: Surge arrester for 220 V circuits, panel installation

Figure 3: Surge arrester for 220/440 V circuits, service entrance installation

for 120 V circuits and 1500 or 2500 V for 220 V circuits. These voltages can be achieved with a 32 mm metal oxide varistor for which the rated clamping voltage is 550 V and 900 V for disks suitable for 120 V and 220 V circuits, respectively.

However, the capability for low clamping voltage might not be attained if installation procedures do not take the connecting lead effects into consideration. Furthermore the proposed IEC practice of several cascaded surge protective devices requires careful coordination of the devices and the intermediate impedance [2], a goal which may not be easy to achieve in routine installation practices.

Table 1

Preferred series of values of impulse withstand voltages for rated voltages based on a controlled voltage situation

Voltages Line-to-Earth Derived from Rated System Voltages Up to	Preferred Series of Impulse Withstand Voltages in Installation Categories			
(V rms and dc)	I	II	III	IV
50	330	550	800	1500
100	500	800	1500	2500
150	800	1500	2500	4000
300	1500	2500	4000	6000
600	2500	4000	6000	8000
1000	4000	6000	8000	12000

Test procedures and standards

The evaluation of surge arrester performance is accomplished by the application of standardized tests which are presumably specific to the operational environment of the arrester.

Performance tests for a low-voltage arrester include sparkover voltage measurement with a specified rise time and also the use of one or more current impulses to demonstrate the capability of discharging a surge either without damage or without the production of excessive discharge voltage during the surge. Figure 4 shows the relationship between these parameters of a gap-varistor design. Because damage to semiconductors is likely to occur during the initial front of the surge before sparkover, the concern over the following discharge voltage is less significant.

Figure 5, however, shows how the gapless varistor can clamp at lower voltages. But, there is a risk of an inductive drop which would add a substantial voltage to

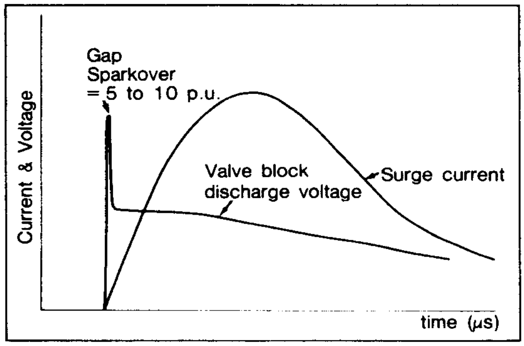


Figure 4: Characteristics of conventional surge arresters

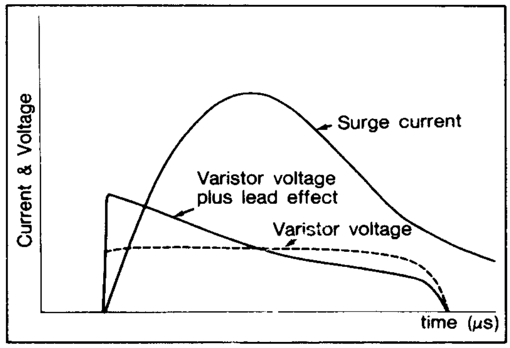


Figure 5: Degradation of clamping voltage caused by misapplication

the intrinsic clamping voltage due to the long connecting leads required under some proposed regulations [3].

Sparkover voltage

Figure 6 shows the sparkover voltage of typical arresters in USA circuits at 120 V line-to-ground and, also, in European circuits at 220 or 440 V between terminals. These sparkover voltages were recorded for a

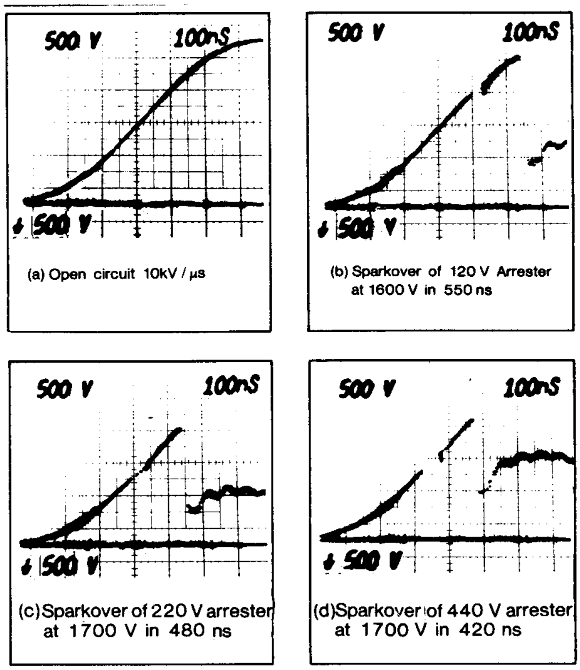
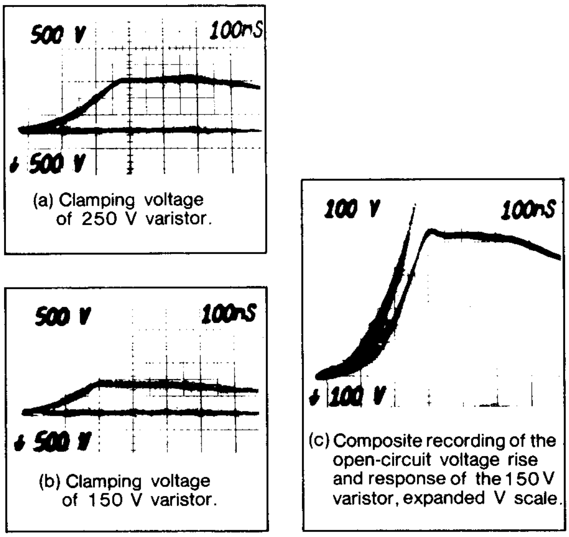


Figure 6: Sparkover characteristics of conventional arresters

10 kV/μs rate of rise (Figure 6a). It is apparent that the gap-type arrester oscillograms exhibit an anomaly at approximately 150 μs before the gap sparks over (Figure 6b, c, d).*

In contrast, the clamping voltage of the varistor (Figures 7a and b) is not only lower, but it is also free from any interference. In Figure 7c, the absence of a significant overshoot in varistor clamping is shown:

- The fast front is the open circuit voltage without the varistor
- The trace to the right illustrates the clamping action of the varistor.



(a) Clamping voltage of 250 V varistor.

(b) Clamping voltage of 150 V varistor.

(c) Composite recording of the open-circuit voltage rise and response of the 150 V varistor, expanded V scale.

Figure 7: Clamping voltage of metal oxide varistors

Impulse current

The selection of the current waveform is not obvious. The use of an 8/20 μs waveform to represent surge currents associated with lightning strokes is well established. Indeed, most standards [4,5] call for an 8/20 μs waveform. Levels may be in the range of 3 to 10 kA crest at the service entrance (Table 2) [4].

The selection of an 8/20 μs wave reflects our present day knowledge of typical lightning currents [6,7]. In addition, the 8/20 μs wave discharges an appropriate amount of energy in the arrester under test.

The question, then, of the likelihood of a 8 μs front propagating along a low voltage system can be raised. Figure 8 depicts a possible distribution of the surge current from a stroke to an overhead system. Taking 50 kA [8] as the median level of lightning stroke, the resultant 5 kA crest is expected, and, with short distances along the service drop, a rise time of 8 μs can be maintained.

* The explanation of this peculiarity is actually quite simple. In real time, the gap fires 150 μs before the display records the event, *but* the oscilloscope used for these tests has a 150 μs delay line. Therefore, the anomaly is the interference created in the oscilloscope by the gap. (Even an EMI option for the oscilloscope is not enough!) This occurrence exemplifies the objectionable effects that a gap can have upon electronic devices.

Table 2

Surge voltages and currents deemed to represent the indoor and outdoor environment and recommended for use in designing protective systems*

Location Category	Low-Impedance Circuits	High-Impedance Circuits
Major feeders, Load center	3 kA 8/20 μs	6 kV 1.2/50 μs
Outdoor installations	10 kA 8/20 μs	10 kV 1.2/50 μs

*Reproduced in part from the IEEE Standard [4] which calls for 3kA at the "load center" and 10 kA at "outdoor installations."

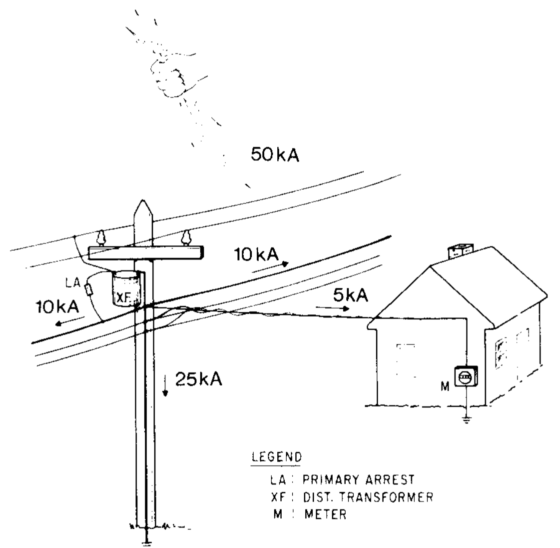


Figure 8: Current division for a stroke to an overhead system

Within these parameters, an 8/20 μs waveform for both the conventional arresters and the candidate metal oxide varistors in service entrance duty appears reasonable. In addition, it is likely to be demanded in the performance of test procedures for arresters – either by customers or by regulatory agencies.

Installation of arresters in panels

Two panels, typical of USA and European hardware (Figures 9 and 10), were wired in the laboratory and subjected to impinging surges of 5 kA crest, 8/20 μs (Figure 11a), that were applied between one phase line and the panel ground. Voltages appearing at the outgoing branch circuits were recorded with oscilloscope probes by using a differential connection after preliminary checking on signal/noise performance of the system. Figure 11b shows the response of the 120 V arrester to this impinging surge. This response will be disscussed in detail with the test results.

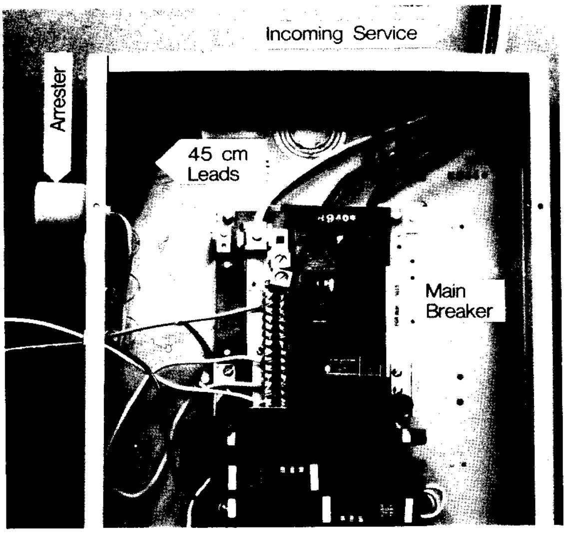


Figure 9: Typical 120/240 V service panel in USA practice, with arrester installed outside panel

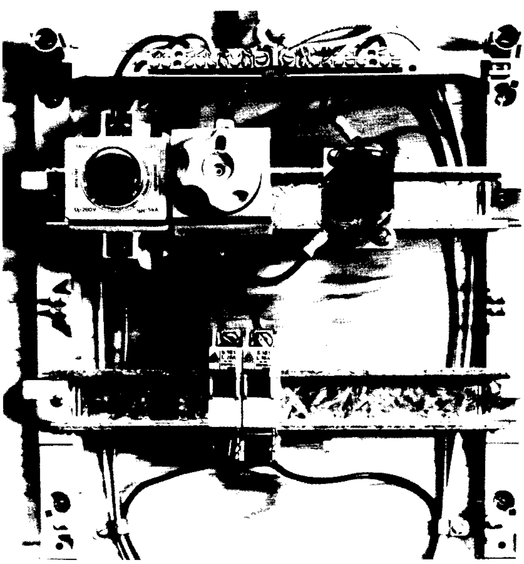
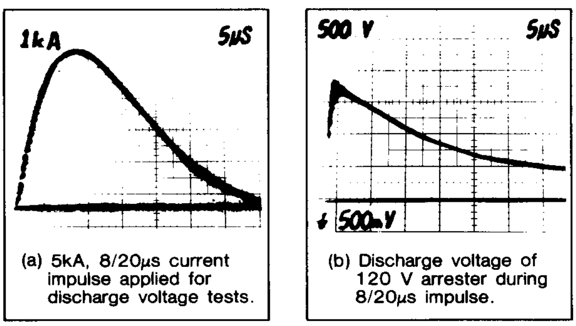


Figure 10: Typical 220/380 V service panel in European practice, with integral arrester connection



(a) 5kA, 8/20μs current impulse applied for discharge voltage tests.

(b) Discharge voltage of 120 V arrester during 8/20μs impulse.

Figure 11: Applied impulse and 120 V arrester response

On the USA-type panel, the 120 V arrester was installed externally to the panel, and the 45 cm long leads were connected to the main entrance lugs of the panel (as implied by the specifications of the National Electrical Code and the proposed UL Document [3]). The 220 V arrester is designed for installation in the panel, and the point-to-point wiring allows short leads for the connection across line and ground (or neutral) inside the panel. The 440 V arrester, as indicated by the manufacturer's suggested installation (Figure 12), is intended to be connected outside at the service entrance rather than at the panel. Consequently, in the laboratory simulation, it was connected 3 m before the panel.

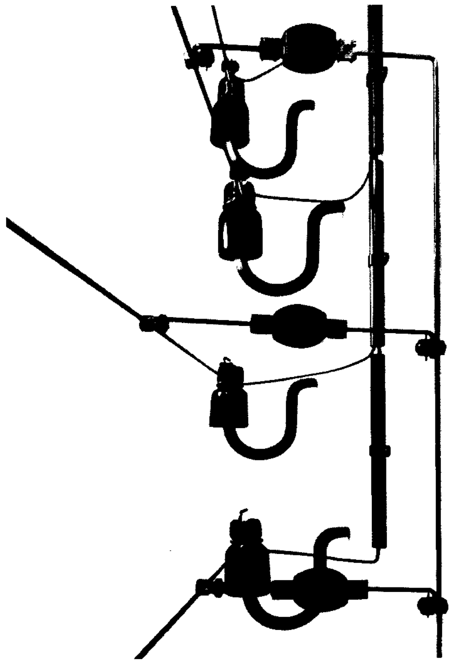


Figure 12: Manufacturer's suggestion for 400 V arrester installation

The 150 V and 250 V varistors (Figure 13) were installed either outside or inside the panel. The installation will be discussed with the test results.

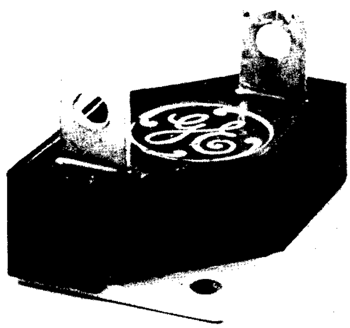
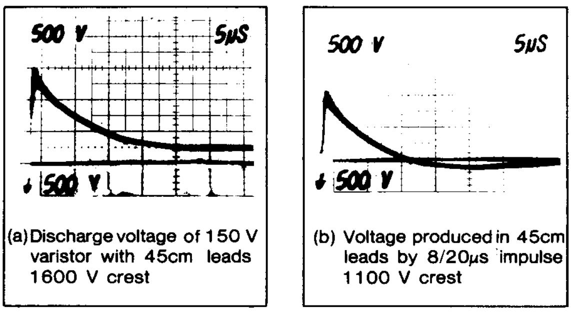


Figure 13: Metal oxide varistor (32 mm) packaged for industrial applications

Test results on discharge voltage

All discharge voltage measurements were made with the surge generator set for the standard 5 kA crest, 8/20 μs current impulse shown in Figure 11a. The clamping voltage of each device and the impedance of its connections may reduce the current to some extent (the charging voltage of the generator was 12 kV), but the same effect would take place under the assumption of a current division resulting from the ratio of the impedances offered to the impinging stroke of 50 kA.

Figure 11b shows the discharge voltage of the 120 V arrester which reflects the applied current wave of Figure 11a. In view of the expectation raised by the low-clamping voltage of the metal oxide varistors, the discharge voltage of the 150 V varistor recorded in Figure 14a seems disappointing. This can be explained easily. The clamping voltage of the varistor is degraded by the addition of the voltage due to the 45 cm leads (Figure 14b). Setting aside the proposed installation requirements and seeking optimum performance, the short connections of Figure 15 produce the remarkably low discharge voltage shown in Figure 16a. For the 220/380 V panel (Figure 10), the layout of components and the absence of conflicting specifications, that is, the promoting of short leads in the standards [9,10], makes possible the equally remarkable low-clamping voltage of the 250 V varistor shown in Figure 16b.



(a) Discharge voltage of 150 V varistor with 45cm leads 1600 V crest

(b) Voltage produced in 45cm leads by 8/20μs impulse 1100 V crest

Figure 14: Effect of long leads

In contrast, the discharge voltages of conventional arresters are higher and contain some high frequency oscillations which may be troublesome. Granted that the voltages are clamped to levels which eliminate the hazards of flashover in the wiring. That is an accomplishment already. But these still relatively high discharge voltages may not be low enough to ensure the survival of electronics connected directly to the mains protected by these arresters.

Figure 17 shows the response of the integral arrester in the 220/380 V panel. The short connections made possible by this arrangement eliminate the problem of added voltage drop. The initial response (17a) of the gap sparkover is well balanced with the discharge voltage during the full impulse (17b). There is, however, the problem of unavoidable collapse of voltage following sparkover, with a possible result of producing interference in connected electronics as well as direct radiation. (See footnote under Sparkover voltage.)

Figure 18 shows the response of the arrester installed at the service entrance. The initial response (Figure 18a) indicates that the additional leads inductance and capacitance can produce peculiar resonances. Nevertheless, the complete impulse discharge (18b) is well balanced with the initial response although the initial collapse reaches the full amplitude during sparkover.

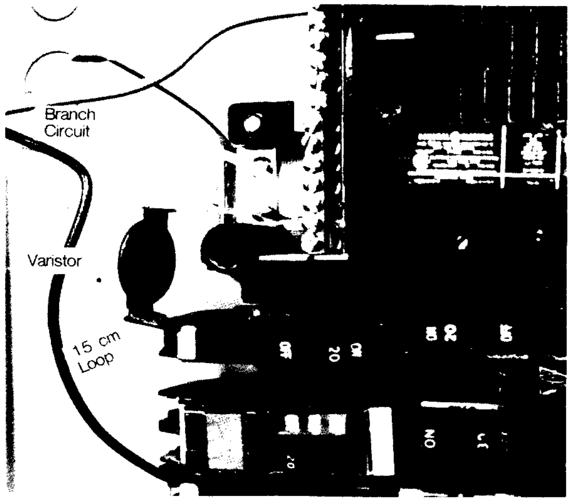
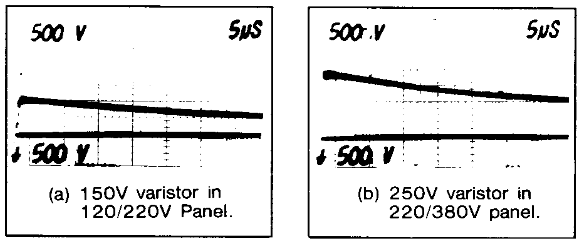


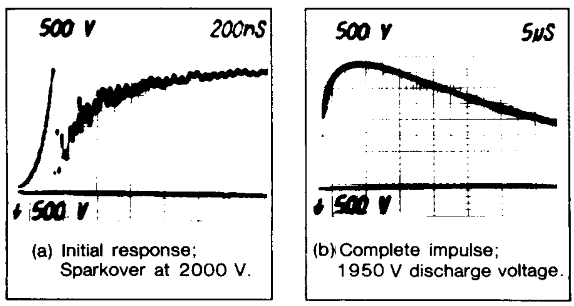
Figure 15: Installation of varistor with short connections



(a) 150V varistor in 120/220V Panel.

(b) 250V varistor in 220/380V panel.

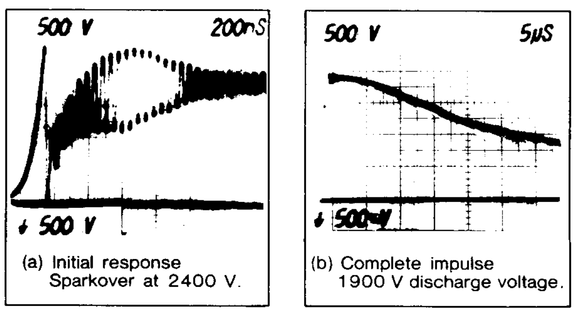
Figure 16: Clamping voltage of varistors with short leads



(a) Initial response; Sparkover at 2000 V.

(b) Complete impulse; 1950 V discharge voltage.

Figure 17: Discharge voltage of 220 V arrester, installed as shown in Figure 10



(a) Initial response Sparkover at 2400 V.

(b) Complete impulse 1900 V discharge voltage.

Figure 18: Discharge voltage of 440 V arrester, installed according to Figure 12

Conclusion

Present technology offers two choices for the protection of low voltage circuits against atmospheric overvoltages:

- Conventional arresters
- Metal oxide varistors.

Although conventional arresters provide protection against the hazards of wiring flashover, they can still allow voltages damaging or disturbing sensitive electronics. Metal oxide varistors, although not yet packaged in a manner convenient for panel installation, not only produce low clamping voltages but they also produce no high frequency disturbances. These benefits, however, will be obtainable only if proper installation procedures are followed.

Acknowledgments

The assistance of Eric Carroll (GETSCO, Paris) and Louis Regez (Landis & Gyr, Zug) in identifying practices and procuring components, and of Alma Bongartgen, Editor, is gratefully acknowledged.

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